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A HELIUM-NEON LASER HIT-KILL SIMULATOR

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Naval Weapons Laboratory
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1. To raise the confidence level in test data, real-time engagement events and resulting attrition would be preserved by an on-board event printer. The ability to attrit in real-time and the additional ability to review engagement events after conclusion of test would: materially assist the test data collection process, reduce the number of data collectors/controllers, and improve the engagement data collection process and test control.

2. Next, it would encourage realistic tactical actions by the tested organizations based upon actual, but nonlethal, weapons engagements. Personnel and commanders would be expected to react in a more realistic manner if their major combat vehicles were subject to accurate, impartial, reliable attrition on the battlefield. When sound tactical actions can be expected to hold attrition to a minimum and deviations from good tactics increase losses, participants are more inclined to "play the game".

3. Third, it will provide battlefield realism. The laser simulator would enable the tester to inject real time attrition into the ongoing test. This attrition would be controllable and based upon attrition data provided by other Army agencies and commands tasked to determine vulnerability of targets and effectiveness of different weapons systems.

4. Finally, the device would improve training. The laser simulator would be available for use by units stationed at Fort Hood when not required for MASSTER test or pretest training. The characteristics of the system would provide greatly increased realism and enthusiastic player participation in all types of field exercises. It was not intended that the laser system serve as a precision gunnery training system.

In late January 1971, a survey of existing hit-kill simulators was made. A British SOLATRON "Simfire" System, manufactured by SOLATRON Electronics Group, was discussed with the engineers at the Naval Training Devices Center (NTDC) in Orlando, Florida. The personnel at NDTC had a thorough knowledge of the SOLATRON system and described it as a sophisticated, computer-controlled tank-to-tank engagement system. It is presently being tested by NATO forces in Europe.

The hit-kill system at Fort Ord, California which is manufactured by Holobeam, Incorporated, Paramus, New Jersey, was observed next. This is a complex, computer-controlled system. Unfortunately, the Holobeam system was still under development at that time and could not be seen in operation.

A discussion was held with Martin Marietta Corporation, Orlando Florida. A laser system developed by Martin Marietta was purchased

by the CDC Armor Agency at Fort Knox, Kentucky. The system is computer-controlled and is used as a tank gunnery trainer. The system utilizes a stabilized platform to compute lead-angle and super-elevation.

Based upon this brief survey, the MASSTER laser committee recommended the following:

1. That MASSTER design and build, in-house, two laser hit-kill simulators.

2. The system should employ a helium-neon (He-Ne) laser, because it is commercially available, relatively inexpensive, and the visible beam is relatively simple to boresight.

3. The detectors should consist of silicon photodetectors and operational amplifiers.

4. The lasers should emit individually identifiable, digitally encoded beams.

5. The lasers should be capable of simulating automatic and single-shot weapons and missiles.

6. The system should mount on any Army vehicle and operate from that vehicle's power.

7. The laser should be eye safe at all ranges.

II. SYSTEM DESCRIPTION

The laser chosen for the project was the Spectra Physics, Model 126, which is an He-Ne laser with a guaranteed minimum light output of 3 milliwatts at a wavelength of 6328 Angstroms (Å). The Model 126 has a transistor-to-transistor logic (TTL) compatible input, permitting the laser to be modulated with a digital pulse train. The lasers used by MASSTER were observed to have an average output of 4.4 milliwatts when operated from 60 Hz to 400 Hz power sources.

Selection of a He-Ne laser made eye safety a serious problem. According to Department of the Army Technical Bulletin 279, Control of Hazards to Health from Laser Radiation, a continuous wave laser is eye safe if its beam power density does not exceed 10^{-6} watts/cm^2. The 4.4 milliwatt beam of the Model 126 is emitted with a diameter of 0.6 millimeters. The resultant energy density at the aperture of the laser was 1.57 watts/cm^2. Two steps were then taken to make this beam eye safe:

The first step toward solving the eye safety problem was the purchase of a telescope from Carson Astronomical Laboratories in

Santa Monica, California. The optics expanded the beam to a diameter of 2.7 inches reducing the power density to 1.2×10^{-4} watts/cm^2. A further benefit of the telescope was its adjustable focal length, allowing the beam spread to be set between zero and twelve milliradians. The adjustable divergence permitted the simulation of the cone of fire of various weapons. For instance, a main tank gun would have a narrow, almost collimated beam while automatic weapons have a large cone of fire. Diverging the beam also resulted in a reduction of the range at which the signal could be detected. This permitted the simulation of a weapon's range limitation.

The second step taken to make the laser eye safe was to obtain the assistance of the U.S. Army Environmental Hygiene Agency, Edgewood Arsenal, Maryland. The laser safety group calculated that the laser system would be safe if the time the beam was on the eye did not exceed one-tenth of a second and had a relaxation time of one-tenth of a second. This information resulted in the construction of a beam oscillator, or nutator.

Several methods of nutation were considered, among them were: oscillating mirrors, fluid prisms with vibrating walls, and mechanical nutation of the laser assembly. Due to the time constraints and the limited facilities at Fort Hood, a mechanical nutator was selected as the most feasible method of oscillation.

Safety requirements dictated that an oscillation frequency be chosen that would cause the beam to traverse a given point within one-tenth of a second. The area to be swept was dictated by the cone of fire of the weapon being simulated. Within these two constraints, the beam pattern shown in figure 1 was picked as both adequate and easiest to produce.

The nutator consisted of a rigid plate which formed the bed for the coaxial laser and telescope. This plate was pivoted at one end and cam actuated at the other. The two cams used operated at 90 degrees to each other, one for horizontal motion and the other for vertical actuation. Both were operated through a single gear train which was driven by an electric motor and a fixed-ratio gear box. The cams were of necessity the most basic type. More complex shapes and resulting complex patterns could be obtained by cutting the cam faces with a numerically controlled lathe. The speed of the beam's passage was controlled by the motor speed and the pattern size, and adjusted by moving the pivot point of the base plate and varying the cam perimeters.

Packaging of the laser presented one major problem, that of proper alignment. The He-Ne laser has a small, adjustable mirror mounted perpendicular to each end of the tube. Mirror allignment, as specified by Spectra Physics, allows a maximum mounting error of .005 degrees. Any such shock or vibration which would result in mirror

misalignment greater than this limit would cause the laser to fail. The problem was solved by using the supporting scheme recommended by the manufacturer. The glass laser-tube framework was supported inside an aluminum box by three mounting pins. Two of the pins formed an axis parallel to the laser tube. The third pin prevented the frames' rotation about this axis as shown in figure 2. All pins rode in bearings with a minimum slip-fit tolerance. The close tolerance was required to eliminate vibration between the framework and the box which could cause the laser tube to vibrate out of position. However, the slip-fit had to be loose enough to allow the box to flex without transmitting twisting and bending forces through the bearings to the frame and thus causing a misalignment of the mirrors.

The fragility of the tube required that the proper shock mounting be observed. The laser mount for the M-60 tank consisted of a one-half inch thick aluminum plate which bolted to the standard xenon searchlight on mounting bolts above the main tank gun. A brace at the front of the plate was necessitated by the harmonics developed between the natural frequencies of the mounting plate and the tank. At one point during testing the tank was operated without the bracing and the laser tube fractured as the tank treads set up a sympathetic vibration within the laser casing.

The laser was mounted on the AH-1G Cobra gunship by a simple bracket designed to replace the minigun and grenade launcher mounts, figure 3. The systems electronics were mounted on a pallet designed to replace the ammunition drums of the AH-1G Cobra, figure 4. The pallet design constraints observed were the size of the ammunition compartment and the natural vibration frequencies of the AH-1G airframe. These constraints necessitated special bracing to eliminate harmonic flexion at the 22-cycles per second frequency.

Boresighting was done using a commerical grade 10-power rifle scope. The scope was mounted on the laser case. The laser and scope were boresighted together in a darkened tunnel which provided an 850-foot range. The laser/scope combination was then focused on the same object as the tank or Cobra sight and at approximately the same range.

The simulation of various weapon types was done by the trigger interface circuitry, figure 5. This circuitry is the electronic link between the standard weapon trigger and the laser encoder. The interface consisted of two main parts, the trigger control circuitry and the basic load counter. The trigger control circuitry caused the laser to fire in a manner that would simulate the firing of the actual weapon (single-shot, rapid-fire, etc.) including delays due to time-of-flight and reload time. The basic load counter could be preset to the number of rounds normally carried for the weapon. The counter is then down-counted until the basic load is expended and the laser is shut off.

The trigger interface circuitry may be operated in any one of three modes:

1. Missile mode. When the trigger is actuated in this mode, a preprogrammed delay is initiated. This delay simulates the missile's time-of-flight. At the end of the delay, the laser is turned on for four seconds. The basic load counter counts each trigger sequence until the "missile load" is expended.

2. Single-shot mode. When the trigger is activated in the single-shot (tank) mode, the laser is fired for 1.5 seconds. At the end of the firing period, an adjustable (15- to 25-second) delay is initiated which simulates the weapon's reload time. During this time, the laser is inhibited. The basic load counter records each trigger sequence until all "rounds" are expended.

3. Automatic-weapon mode. When the laser is in the automatic mode, the laser will fire continuously for the duration of the trigger pull. The basic load counter counts the time, in tenths of seconds, the trigger is depressed. At the end of the preset time period, the basic load is expended and the laser is turned off.

The modulation signal produced by the encoder was a 21-bit data train which was clocked at a 10 KHz rate. This clock rate was chosen to allow full laser output power. As the frequency of laser modulation was increased, the signal power would decrease.

The signal began with a 6-bit synchronization code followed by a 4-bit field defining weapon type (main tank gun, machine gun, missile, etc.). The next field was an 8-bit signature identifying the specific laser. This field was preceded by a blank and followed by two blanks. Both the weapon type and laser signature were adjustable by setting a series of thumbwheel switches.

Two different detector/amplifiers were built and tested. The first model was a United Detector Technology, Inc., UDT-500 photodiode with a built-in amplifier. An optical filter for 6328 A ± 50A was used on this photodiode, reducing the field of view to a 15-degree cone. Since the photodiode and amplifier were sealed in a single unit, they were already DC-coupled. This caused the photodiode to respond strongly to the DC signal produced by sunlight. The gain of the amplifier had to be kept low to avoid saturation in bright light. This detector/amplifier had three additional stages of amplification with variable gain and hard limiting. The operational amplifiers used were of poor quality resulting in a very noisy circuit which had a tendency to oscillate.

For the second detector a UDT PIN 10-D photodiode was selected since it does not have a built-in amplifier. The was desirable as it allowed the photidiode to be capacitor-coupled to the first

stage of amplification. This eliminated the problem of amplifier saturation in sunlight. The photodiode was operated in the photovoltaic mode which has lower dark currents than the photoconductive mode. The same 6328 Å $\pm$ 50A optical filter was used. The sensitivity of this photodiode is a minimum of .20 amps per watt for the He-Ne laser frequency of 6328 Å.

The second detector/amplifier used low noise operational amplifiers and a two-transistor automatic gain control. The first stage of amplification was followed by the automatic gain control (AGC) circuit. The AGC circuit was used to maintain maximum amplification while preventing the following operational amplifier from going into saturation. Such saturation would cause an undesirable stretching of the pulses and eliminate the synchronization with the decoder. The AGC circuit was followed an an additional operational amplifier stage with a clipped output. This last stage converted the signal to TTL logic levels. The noise immunity of the system was improved by detecting a signal level at the output of the AGC circuit. The input to the TTL gate was then shut off if the signal level was below a set threshold. All stages were capacitor-coupled and filtered to provide a bandpass filtering for a pulse frequency of 10 KHz to 20 KHz

During the testing of the hit-kill simulator, three detectors with their associated amplifiers were placed in the vulnerable areas of the vehicle. The outputs of the amplifiers were ORed in the decoder. The decoder then processed the incoming data after recognition of the synchronization code which preceeded the 4-bit weapon-type code and weapon serial number. The 4-bit weapon-type code was used to determine the probability of kill. A kill was permitted when the incoming asynchronous data was in coincidence with the free-running pulse train with a variable duty cycle gate, i.e., if a weapon had a 90 percent probability of kill, then the gate would be open for 90 percent of the time to allow for the passage of the 4-bit weapon-type code. If this code was successfully decoded on two successive decodes, a kill was declared.

III. SYSTEM PROBLEMS AND SHORTCOMINGS

One potential shortcoming in the system was the use of the He-Ne laser. The glass enclosure will leak Helium which shortens the tube's lifetime. It should be noted that during six months of testing only one laser was broken, and this was due to careless mounting. A three-hour test in the field with the laser properly mounted on the M-60 tank resulted no damage to the laser.

Dust and dirt on laser mirrors and detectors is a serious problem. The laser could be protected by enclosure in a dust- and water-proof container. The lens and the detectors must be wiped clean once or twice a day with a soft cloth. No other practical solution to the dust problem was found.

The size and power requirements of the He-Ne laser are large when compared with those of the gallium arsenide laser. The Model 126 laser measures 18" x 4" x 6" and requires 150 watts of power. The power supply was contained in a separate unit and was bulky. In comparison, a gallium arsenide laser may be no larger than a flashlight and require 20 - 30 watts of power.

In this initial prototype the probability of kill was arrived at rather crudely and was considered an acceptable trade-off, made in the interests of system simplicity. A true kill probability calculation would consider such things as type of weapon, type of target, terrain, weather and range.

Radio frequency interference (RFI) was a problem encountered with the detectors and the digital section of the system. All cabling used on the helicopters had to be coaxial to eliminate cross talk and RFI interference from the onboard radios. The encoder and decoder were also shielded to prevent RFI from the helicopter's electronics. Detector RFI was reduced by covering each detector with copper screening which was bonded to the detector mount.

The field-of-view of the photocell detectors was only 15 degrees. Several experiments were conducted with fisheye lenses and parabolic mirrors with no great success. The problem was sidestepped, due to lack of time and materials, by placing multiple detectors at vulnerable points on the targets.

Another problem encountered was engagement of a single target by several lasers. Simultaneous reception of two or more signals resulted in a garbled signal which was a combination of all the signals being received. In spite of this the time required to kill a target was 4.2 milliseconds for this system and the probability of a second signal occurring within this 4.2 milliseconds was considered to be insignificant.

The major problem encountered during testing was the design of the XM-28 turret system of the AH-1G Cobra gunship. The XM-28 turret was designed for area fire weapons with visual feedback for correction and does not have an aiming apparatus accurate enough to paint a target with a 3 - 5 mil laser beam at ranges greater than 1200 meters. Pointing repeatability of the XM-28 turret was found to be no better than 20 mils. Several methods were investigated to overcome this shortcoming. A television camera was mounted on the turret, figure 6, with a monitor positioned in the cockpit. This too had a range limitation problem as well as a stabilization problem. Another method was to mount a laser with a set of stabilized optics on the panograph of the XM-28 turret system. This offered the most promising results.

IV. RESULTS

The system demonstrated at Fort Hood established the feasibility of a laser hit-kill simulator system for use in MASSTER testing. The results of the prototype laser hit-kill simulator with its shortcomings and problems were the guidelines in the preparation of the Weapons Engagement Socring System (WESS) specifications. This system is now under procurement by MASSTER.

Such areas as the stability and inaccuracies of the XM-28 turret system of the AH-1G Cobra gunship, the limited field of view of the photocell detector as a function of filter bandwidth, the probability of kill circuitry limitation and the size and power consideration were areas that were covered in great detail in the WESS specification.

V. CONCLUSIONS

Based upon MASSTER's experience with the He-Ne laser system, the following conclusions were derived:

1. In any tactical military system, size, power and reliability should be prime considerations. For these reasons, it was recommended that the solid-state gallium arsenide laser should be used in future systems of this type.

2. The problem of eye safety with the continuous-wave He-Ne laser was greater than with the solid-state GaAs laser which is Q-switched. A safe Q-switched laser has a higher peak power than a safe continuous-wave laser.

3. Helicopter vibration is a problem for any laser system. A possible solution to this problem is to use a rate-gyro package to stabilize the gunship turret.

4. Dust and dirt on lenses and detectors is a problem with any system. Occasional cleaning of lens and detector surfaces appears to be the only solution.

5. Interference from multiple signals on a single detector is not a significant problem if the duty factor of the laser is kept as low as practicable.

6. Mechanical oscillation of the laser beam for the purposes of eye safety and weapon simulation is feasible and relatively simple to achieve.

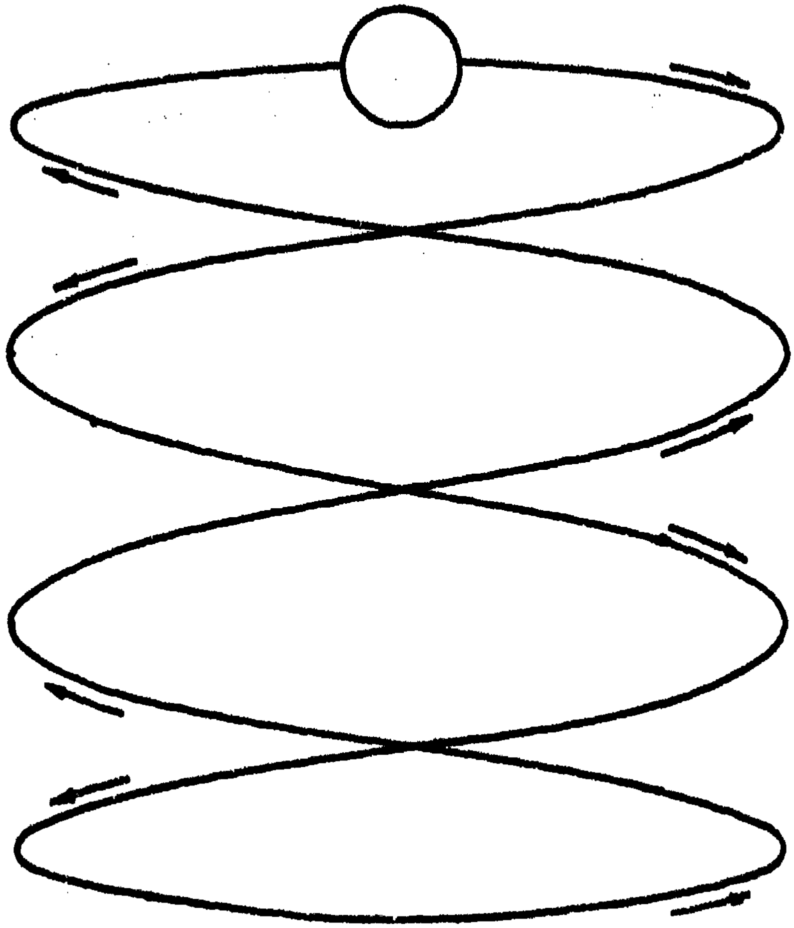

Figure 1

Nutated Beam Pattern

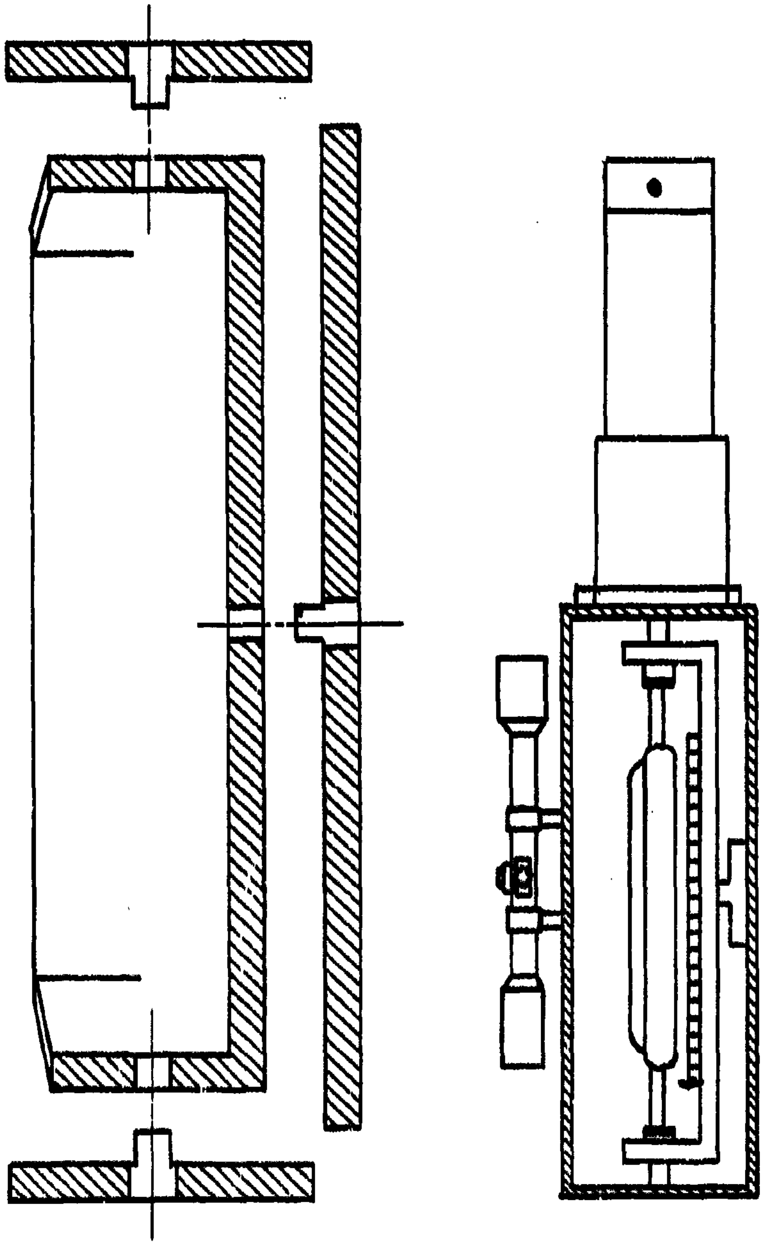

Figure 2

Exploded View of Mounting and
Cutaway of Mounted Laser Tube

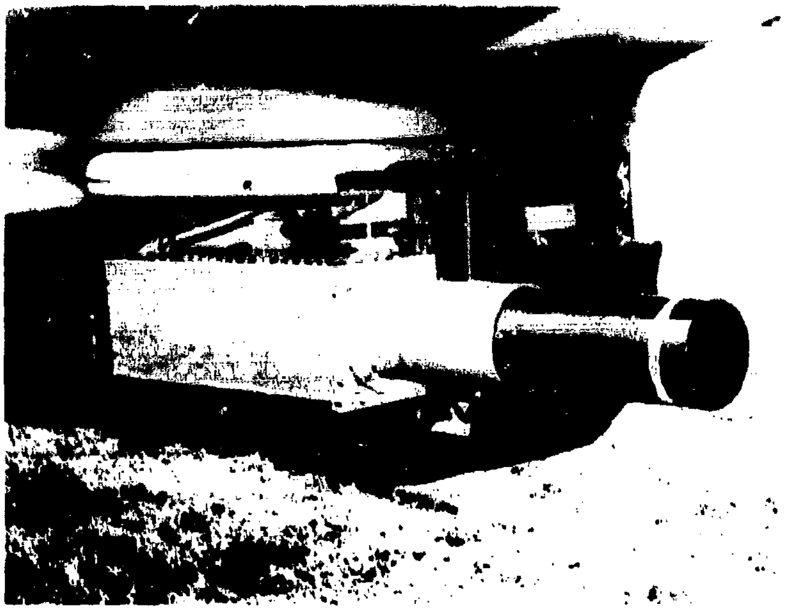

Figure 3 Laser Mounted on AH-1G Cobra

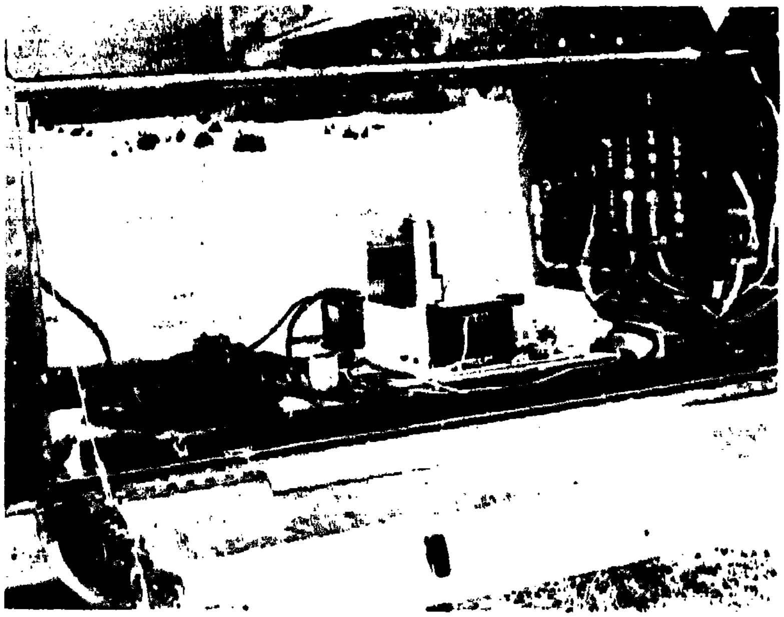

Figure 4 Pallet in AH-1G Cobra Ammunition Bay

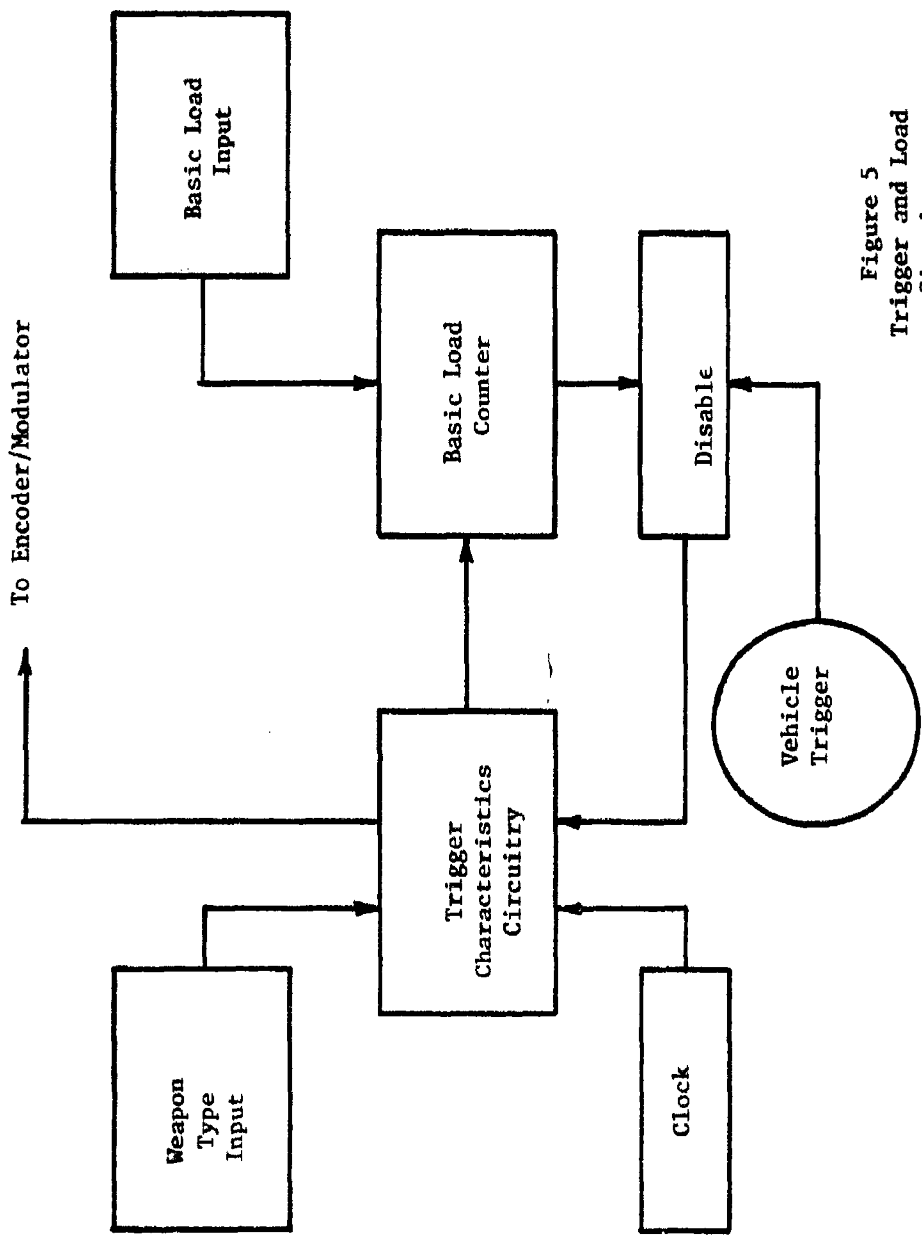

Figure 5
Trigger and Load Circuitry Block Diagram

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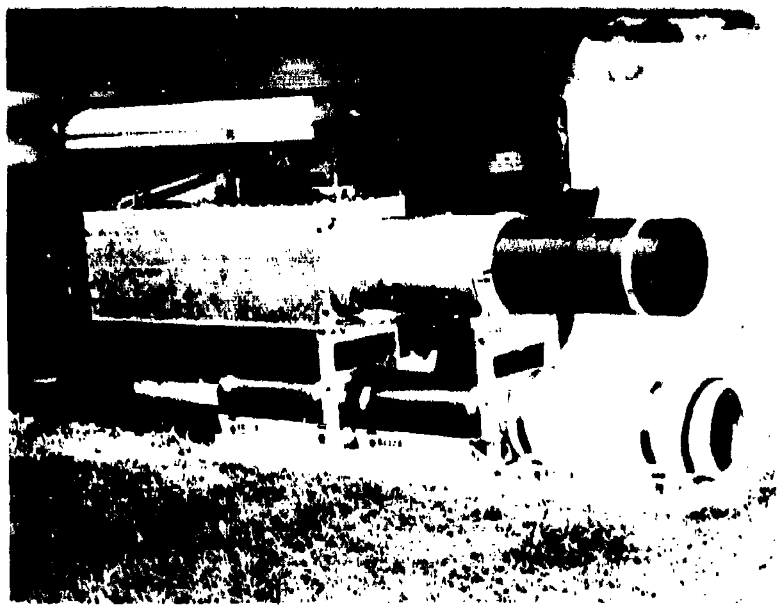

Figure 6 TV Camera and Laser Mounted on AH-1G Cobra

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